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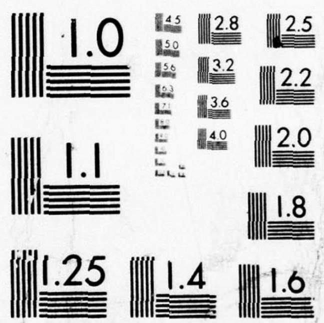

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Balloon-Borne Ion Sampling Package

Combined Final Report

J. R. Olson, R. C. Amme, J. N. Brooks, D. A. Steffen,
R. E. Sturm and D. G. Murcray

14 December 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A mass filter package for atmospheric sampling in the stratosphere has been designed and constructed so that ambient positive ions can be detected in one mode of operation (PI) and ambient negative ions in a second mode of operation (NI). The range of the quadrupole mass filter is 1-150 amu. Any one of the 150 mass positions can be selected for a fixed peak operation, or the total range can be covered in a continuous sweep at the rate of 300 amu per second. Filtered ions are individually counted. The atmosphere is sampled through a

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20. Abstract (cont.): valved 0.03 cm diameter orifice which has a conductance of about $9(10^{-3})$ liters/sec and width-to-thickness ratio greater than 10. Ambient temperature, ambient pressure, atmospheric electrical conductivity and cosmic ray ionization detectors are also part of the package. An on-board clock and logic circuitry control the gathering of data. However, the mass filter operations can also be preferentially controlled via telemetry. Data are concurrently recorded with an on-board digital tape recorder and telemetered to earth for real time data analysis. The entire package has been designed and constructed to minimize contamination of the atmosphere being sampled. Preliminary results from a recent flight show evidence for the presence of hydrated protons in the stratosphere.

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I. Introduction

In order to further our understanding of the stratosphere, in situ measurements of ambient ion concentrations are desirable. Since many of the ions of interest are presumably $H^+(H_2O)_n$ clusters, it is of the utmost importance that negligible amounts of water (and other contaminants) are carried aloft by the experiment to avoid significant alterations of the ambient ion distribution.

Proof that one can indeed construct and fly a clean balloon-borne package was demonstrated with an earlier instrument that had the capability of measuring neutral constituents.[1,2] Flight results indicated that water concentrations in the stratospheric gas that was sampled were less than 40 ppm.[3,4] The ambient ion distribution will not be significantly altered with water concentrations of that amount.[4] PI measurements attempted with the above instrument indicated that a larger orifice was desirable to increase the ion current and thus improve the signal-to-noise ratio. This requirement necessitates a high pumping speed to handle the increased neutral gas flow.

The balloon-borne rf mass filter package described in this paper utilizes a liquid helium cryopump having a pumping speed in excess of 5000 ℓ/sec. With an orifice conductance of $9(10^{-3})$ ℓ/sec, atmospheric samples have been obtained at ambient pressures as high as 14 torr with excellent signal-to-noise ratios.

Contamination of the atmosphere near the gas entry region is minimized as follows. The gondola bottom and landing gear are constructed of stainless steel; the sealed gondola is vented several meters up the load line; no adhesive tape, crush pads, or other outgassing material is allowed on the gondola; and data are taken while the balloon is descending. Alternatively to the latter, one could suspend the instrument package several hundred meters below the balloon, parachute, and balloon control apparatus. In either case, sampling during descent ensures a flow of air towards the sampling orifice, and this should increase the probability of getting ambient ions through the orifice.

II. The rf Mass Filter

A schematic of the mass filter is presented in Figure 1. The vacuum chamber is constructed entirely of 304 SS and all joints are heliarc welds. Chamber walls are 0.16 cm thick. Access is obtained through Varian Conflat flanges, some of which are shown. The entire chamber is designed so that it can withstand bakeout temperature up to 250° C.

Special consideration is given to the gas entry problem. The fast acting (300 msec) valve (A), described elsewhere,[5] repeatedly seals well enough to maintain chamber pressures below 10^{-8} torr between sampling operations. The sealing mechanism swings completely away from the gas entry region during sampling operations, minimizing any disruption of the ambient ion distribution in the vicinity of the sampling volume. Also, to overcome the possibility of charge buildup on the package, the 7.5 cm-diameter plate (B), containing the orifice, is insulated from the rest of the chamber with a polyimide o-ring so that a "draw-in" potential (V_p) can be applied. This potential is selected by telemetry (TM) command and any value between +20v and -20v in 160 mv steps is available.

A 0.03 cm diameter orifice with a width-to-thickness ratio greater than 10 and a measured conductance of $9(10^{-3})$ liters/sec is located at the center of the orifice plate. The plate is EDM machined from a single piece of tungsten carbide. In order to provide a sealing surface for the swinging retractable polyimide plunger, the area near the orifice is given a 1 micrometer polish. Unless a foreign substance lodges between the polished surface and the plunger, this combination provides a reliable vacuum seal. The conical region behind the orifice allows for rapid gas expansion and also serves to focus the entering ions into a beam along the axis when the first electrode inside the orifice is maintained at an ion accelerating potential with respect to V_p. The three electrodes (C) consisting of the ion accelerating electrode, the ion focusing electrode, and the quadrupole entrance electrode essentially form an Einzel lens. Since the decelerating mode of operation requires a lower focus potential leading to less chance of loosely-bound cluster-ion breakup, that mode was chosen. Laboratory tests have shown that for the potentials selected, $V_p \pm 10$ v for the accelerating and quadrupole entrance electrodes and $V_p \pm 7$v for the focus electrode, where the + and - stand for NI and PI operations, respectively, 65 - 70% of the ions which pass through the orifice can be made to enter the mass filter. Of course the quadrupole shield potential (V_s) also is maintained at $V_p \pm 10v$ and the dc operating voltages applied to the quadrupole rods are referenced to this same value. A more detailed picture of the gas entry region is shown in Figure 2.

The rf quadrupole mass filter (D) is a Finnigan Instruments product and is identical to the unit used in their model 400 mass spectrometer. The quadrupole rods are solid cylinders, 0.64 cm diameter by 14 cm long. A Johnston Laboratories MM-1 electron multiplier in a shielded enclosure (E) is used in an on-axis configuration to detect the filtered ions. The lens, mass filter, and multiplier are put together as a unit which is rigidly mounted to, but electrically insulated from, the vacuum chamber base plate. Electrical connections are made to the quadrupole rods from feedthroughs (F) and to the focusing electrode and quadrupole shield through a standard instrumentation feedthrough. Connections to the multiplier are made through high voltage feedthroughs welded into the chamber wall (not shown).

To meet the high speed vacuum pumping requirements and the ballooning requirements of low weight and low power consumption, a liquid helium cryopump was designed and constructed. A simplified schematic of the cryopump is shown in Figure 3. The 4.5 ℓ liquid helium container (a) is constructed of stainless steel except for a copper plug in the bottom to provide good heat transfer from the pumping surface (b). The radiation shield consists of an outer section (c) and an inner section (d) which are mechanically connected via two connecting archways (not shown) that allow the electrical connections to be made to the mass filter and detector. The entire cryopump assembly is supported from the top by a thin-walled (0.025 cm) stainless steel tube. A copper cylinder (e) is brazed onto this tube to provide support for the radiation shield. The cold helium vapor is forced to spiral along the inner surface of the tube in order to cool the copper cylinder and hence to help cool the radiation shield. The pumping surface and the radiation shield are both constructed of OFHC copper and all surfaces are gold-plated for good reflectivity and low emissivity.

Lateral support for the assembly is provided near the center. Nichrome wires (dashed lines) are pulled taut and spot-welded from plate (f) to cylinder (g) which fits over the top of the inner radiation shield. Then, a second set of wires is pulled taut and spot-welded from the cylinder to a ring (h) that is held with set screws to the outside wall. This arrangement provides for low thermal conductivity so as to keep the helium boil-off rate as low as possible.

The whole assembly is simply lowered into the mass filter chamber and the mating Conflat flanges are then bolted together. The high pumping speed is achieved by leaving a considerable area of the pump open to the incoming gas flow. This increases the helium boil-off rate, but helium hold times greater than four hours still obtain with this design.

If desired, dry CO_2 or some other dry condensible gas can be bled into the chamber after the pump is cold to form a layer of frost. A spare access port, Figure 1 (G), may be used for a leak valve. The frost mode of pumping is more efficient, as pumping also occurs by burial of atoms in the frost.[6] Of course, a frost composed of atmospheric gases is soon built up after sampling operations begin. Tests in this laboratory have shown that helium is also efficiently frost-pumped in concentrations normally present in the atmosphere. A 2 ℓ/sec VacIon pump (H) also helps to pump helium, but its primary function is to monitor the chamber pressure during flight.

Another access port, with valve (J), is used for connection to an external clean vacuum pumping system.

III. Mass Filter rf/dc Generator

The completely solid state rf/dc generator has an input power requirement of less than 20 watts and allows the analysis of mass numbers from 1 to 150 amu with a resolution, if desired, of 0.8 amu. A 2.70 MHz crystal in an oven provides the ultrastable frequency source. The maximum rf peak and dc voltages required are given by[7]

$V = 7.214\ Mf^2 r_o^2$ and $U = 0.1678V$, respectively, where

M = the largest mass number to be analyzed in amu,

f = the operating frequency in MHz, and

r_o = the distance from the quadrupole axis to the rods in cm.

For the r_o of 0.275 cm in this instrument, the maximum rf peak voltage is 600 v and the maximum dc voltage is $\pm$ 100 v relative to the shield potential V_s. Inherent in the rf/dc generator is the necessary circuitry to operate in a fixed peak (FP) mode and in a 0-150 amu scan mode at the scan rate of 300 amu/sec.

Provision is also made for holding the dc voltage at V_s during either mode of operation while the rf voltage behaves normally. This results in a high-pass filter where only ions with mass greater than the cutoff value of M_o traverse the quadrupole. In the FP mode M_o is selectable between amu 1 and amu 117 and remains constant during the operation. In the scan mode M_o sweeps from amu 1 to amu 117; i.e., all ions are allowed to traverse the quadrupole at the beginning of the scan but only ions with amu >117 are allowed through at the end of the scan.

Figure 4 shows a simplified schematic of the rf/dc generator. The dc voltage is produced first and is then used to establish the amplitude of the rf voltage. In the scan mode, a gate whose length corresponds to the total mass range to be scanned unclamps a precision integrator and the resultant ramp is amplified to produce exactly the proper balanced (push-pull) dc voltage. For the non-sweep fixed peak mode, the selectable voltage corresponding to the desired mass peak comes from a D/A converter. High quality operational amplifiers are used to ensure exact gain and fidelity. The inverse of this signal is produced in the same fashion by inverting the waveform.

The dc voltage controls the amplitude of the rf voltage by modulation of the 2.70 MHz crystal oscillator signal with a field effect transistor. The class B push-pull output stage, which consists of a tuned step-up output transformer, amplifies the modulated signal and provides the mass filter rf voltage. This output rf signal is detected and compared with the dc value at the input of an operational amplifier to ensure rf amplitude fidelity. Class B operation is used in the output stage in order to reduce dissipation and thereby ease the battery load.

IV. Mass Filter Data Handling

Ions incident on the first dynode of the Johnston focused mesh electron multiplier produce output pulses of 10 nanoseconds width at half amplitude. The multiplier operating voltage is adjusted so that the average pulse height is greater than the maximum peak value of rf pickup from the quadrupole. Voltages near 3.5 kv typically result in pulse heights greater than 25 mv when driving a 100 ohm load. The pulse amplifier has extremely wide bandwidth (50 MHz minimum), is internally well shielded, and has available gain of several thousand if required.

In order to be compatible with the maximum mass filter resolution of 0.8 amu, the pulse counters accumulate counts in blocks of 0.2 amu (667 microseconds). Since the output pulse rates of the Johnston multiplier are less than or equal to 10^8/sec (depending on the multiplier gain), the maximum theoretical number of counts in any one block will be 6.67 (10^4) which can be resolved by 18 bits of binary information.

The 18 bits of mass filter data per sample are arranged into three characters (6 bits and an odd parity bit) for on-board recording with a specially designed light-weight tape recorder. The standard 10-inch reel of 1/2 inch tape will play back on all major computers having 7-track tape transports. Data are recorded at the rate of 4500 characters/sec with a density of 556 characters/inch. Mass filter data are also routed to the TM digital encoder where they are organized into frames of 128 nine-bit words (8 data bits and a parity bit) prior to transmission.

V. Auxiliary Measurements

Measurements in support of the mass filter data are also obtained with this package. A detector based on the design of Neher[8] determines cosmic ray ionization rates in the atmosphere. The ionization chamber is a stainless steel sphere (26.7 cm diameter with 0.05 cm wall thickness) filled with argon to a pressure of eight atmospheres at 20° C. It is sensitive to electrons with energies greater than 1 MeV and to protons with energies greater than 10 MeV. A -195 v sweeping potential is applied to the central electrode and an electrometer converts the chamber ionization current to voltage levels compatible with the digital sampling circuitry.

Atmospheric electrical conductivity is measured by means of a blunt probe of the same dimensions as the orifice plate. It is mounted 7.5 cm below the gondola near the side opposite the gas entry region. Positive and negative voltages are applied to the probe in sequence so that negative and positive conductivities may be measured.

Thermistors are used for ambient temperature measurements and for monitoring temperatures at several locations inside the gondola.

Ambient pressure is measured with three potentiometer-type absolute pressure transducers which cover the ranges 0 - 760 torr, 0 - 130 torr, and 0 - 26 torr, respectively.

VI. Command Electronics

The function of the command electronics is to:

(A) monitor and/or command the operation of all on-board data collection devices,

(B) interface the on-board telemetry for transmission of data to the ground station and for optional ground control of mass filter operations, and

(C) control the on-board tape recorder.

Each section of the command electronics periodically (once each minute) fulfills the task for which it is designed. At the beginning of each new minute, the circuitry is reset to repeat the operation and no knowledge concerning operation during previous or future minute intervals is required. The largest portion of the command electronics is digital, and CMOS logic circuitry is used wherever possible since it requires very little power and has excellent noise rejection characteristics. All of the circuitry is fabricated on printed circuit boards contained in one card nest. See the block diagram in Figure 5.

The environmental data from inside and outside the gondola, in addition to the on-board time and operational status of the mass filter, are referred to as "housekeeping" data and no special commands, either on-board or from ground control, are required for obtaining them. However, the command electronics does control the operation of all equipment that is necessary for a mass filter operation.

An on-board master sequencer can be quickly programmed before launch with the desired number and order of operations. Fixed-peak programmed operations are limited to eight different values, with three of these presently utilized for high-pass operations. The master sequencer which consists of 2 x 512 bits serial memory is capable of storing 512 minute block commands. This is sufficient for an 8-hour flight. The on-board clock is initiated when the master reset signal becomes inactive and housekeeping data then are both recorded and transmitted (during on-line operation) once each minute. Scan operations will occur during the minute block asked for by the master sequencer. In addition, ground control is able to override the on-board program in that a programmed operation can be canceled or replaced with another operation and an operation can be initiated where none was scheduled. Also, there is no restriction on the FP value that can be commanded.

VII. Telemetry

In order to have reliable in-flight commands and on-line data processing, a telemetry (TM) system which transmits correct commands and which does not degrade the data is required. Such a system was designed, constructed, and tested under a separate ARO grant (see reference 9 for details). A block diagram of the system is shown in Figure 6.

The command encoder generates a 24 bit serial bit stream of which 16 bits are command data information, 1 bit specifies whether the command is a data word command or a discrete command, and the remaining 7 bits are used as code words for beginning of message and end of message characters. The serial bit stream thus produced enters a frequency shift keyed generator where two tones are generated that represent the binary values. To ensure that no false commands are accepted due to low signal level, spurious commands from interference, or random noise, the command signal is transmitted twice. The on-board decoder then compares the two 24 bit words bit for bit and the command is only accepted as valid when there is perfect correlation. Only one or the other of a 16 bit data word command or a discrete command can be transmitted at a given time.

The 16 bit data word command is structured to provide for the following choices: operate or not operate, FP or scan, NI or PI, high-pass or band-pass, value of FP desired, value of orifice plate voltage for NI operations, and value of orifice plate voltage for PI operations. The plate voltage values are latched in and will remain at the selected value until a change is requested while the other choices pertain only to the next minute block. Discrete commands are used to turn the transmitter on or off, switch two high voltage supplies on or off, obtain TM control of valve operations, open or close the valve, and reset the microprocessor. It should be noted that the capability of the command system exceeds its current use.

The on-board data encoder consists of a microprocessor unit (MPU), 500 words of random access memory (RAM), a programmable read-only memory (PROM), and two peripheral interface adapters (PIA). Data are organized into frames of 128 9-bit words and are serially transmitted via pulse code modulation at a 50 kilobits-per-second rate. In order to be decoded, the frames must be transmitted at a uniform rate, but the data to be included in the frame is not received in synchronism with this transmission. The MPU is used to solve this problem. It can execute 72 instructions, most of them in less than 5 microseconds. Therefore, the MPU, which must output one word every 180 microseconds, has ample time to make up a frame from incoming data that is asynchronous with the output.

The PROM contains the program for constructing the frame. The frame in use for the current flights consists of 5 sync words used to recognize position in the frame, 2 words from analog data inputs, and one flag word which is used to indicate if the following 120 words will contain digital data from the command electronics.

The 16 analog data inputs are sampled in sequence with a 16 position multiplex switch and then digitized with a 12 bit A/D converter. A PIA is used to interface these data with the data and address bus of the MPU.

Digital data from the command electronics are entered 8 bits at a time from a separate PIA to a shift register. An odd parity bit is generated from these 8 bits to make a 9 bit word which is then shifted to the transmitter at the 50 kHz rate.

Appropriate interfacing and software at the ground station allow the data to be displayed on a CRT terminal in real time. Data are also stored in the computer for later hard-copy printout at convenient times during or after the flight.

VIII. Measurements

Preliminary data were obtained on a recent flight of this instrument. Launch was at 0725 MDT on 22 June 77 at Holloman AFB, New Mexico. The flight plan called for ascent to 32 km and then descent at about 2.5 m/sec until flight termination. Operations were to commence shortly after float altitude was attained and then continue during the descent portion of the flight. Mass filter resolution for this flight was set to about 3-4 amu in order to maximize quadrupole transmission.

Unfortunately, a pressure readout failure occurred about an hour after launch. It became impossible to monitor the vacuum chamber pressure and hence to ascertain whether the valve opened for all operations. However, residual gas pressure in the chamber after the flight indicated that the valve had indeed opened for many of the operations.

Results from a PI scan operation are presented in Figure 7. In this mode, 29 scans from 0-150 amu are co-added channel by channel. No counts appear before amu 81 and beyond amu 113. Some scattered single and double counts appear between amu 81 and amu 106, but the major portion of counts appears between amu 106 and amu 112 with a peak at amu 109. Since the accumulation time per channel is 193 msec the maximum number of 7 counts per channel corresponds to 360 counts per second or 40 ions counted per cm^3 of air sampled. At the time of this operation, plate voltage was -0.16v, altitude was 27.2 km and the descent rate was 2.8 m/sec. A PI scan commanded shortly after this with the valve closed showed zero counts.

Earlier in the flight, several FP operations were commanded for amu 55, amu 73, amu 91, and amu 109 which correspond to $H^+(H_2O)_n$ clusters with n = 3, 4, 5, and 6 respectively. Background operations at amu 9 were also commanded. In this mode of operation, sensitivity is about 150 times greater than for scan operations.

With a plate voltage of 0 volts, ion counts were obtained in successive operations two minutes apart at amu 73 and amu 91. Respective count rates were 90 and 135 ions per second which correspond to 10 and 15 ions counted per cm^3 of air sampled. The corresponding altitudes were 31.7 km and 31.5 km so the descent rate was about 1.7 m/sec at that time.

At 30.9 km altitude and a descent rate near 1 m/sec, a few counts were observed during an operation at amu 109. Plate voltage was -0.5 v. The count rate was 0.7 ion per second or 0.08 ion per cm^3 of air sampled. This is greater than the average background rate of 0.14 count per second.

Some operations resulted in zero counts and it is quite possible that the valve did not open for those operations.

No attempt was made to make an absolute calibration of the instrument.

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X. Personnel

The following is a list of participating scientific personnel involved in this research. No advanced degrees were earned relative to this project.

Robert C. Amme
James N. Brooks
David G. Murcray
John R. Olson
Dale A. Steffen
Ronald E. Sturm
John Van Allen
Frank E. White

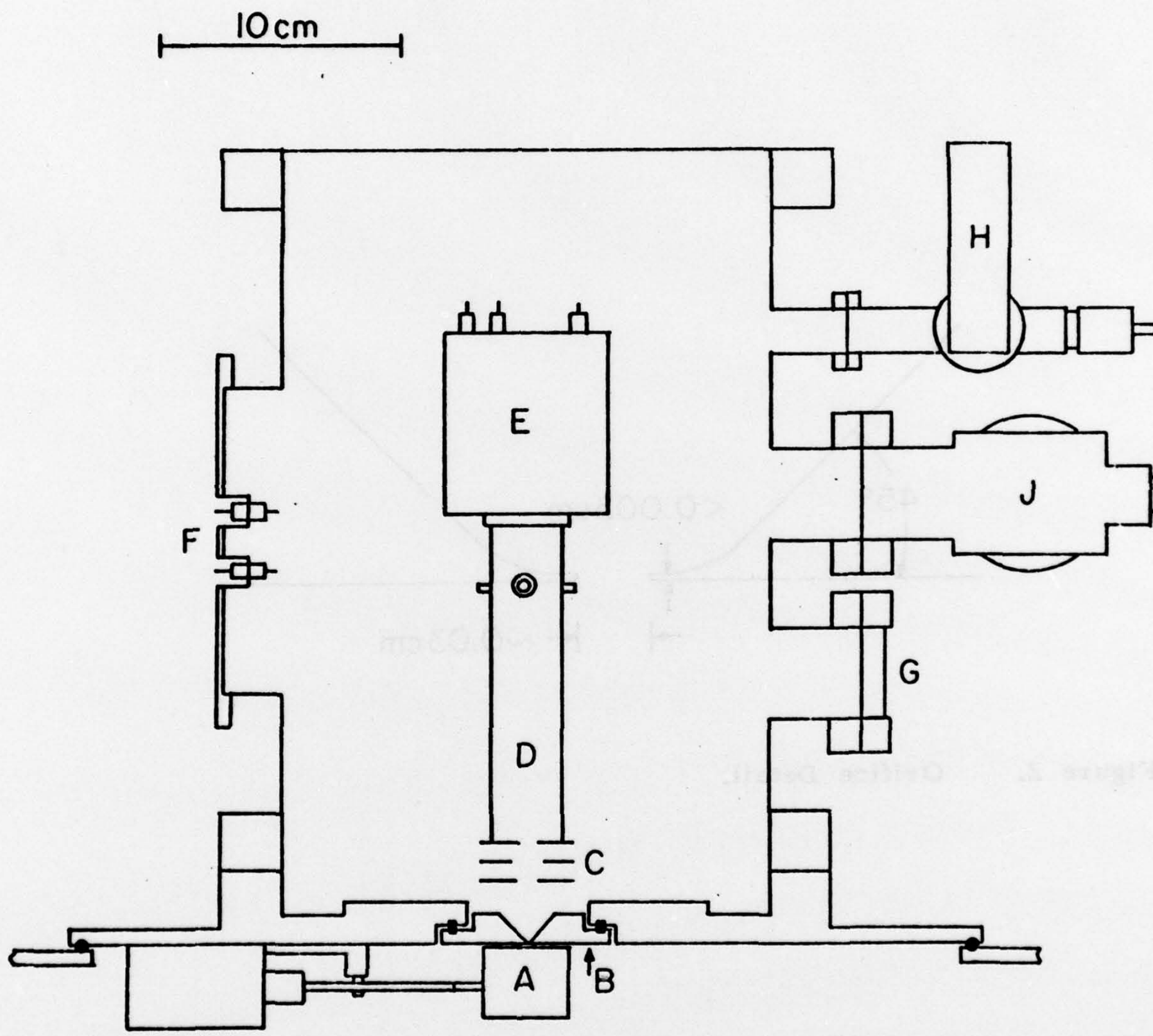

Figure 1. Mass Filter Vacuum Chamber Schematic.

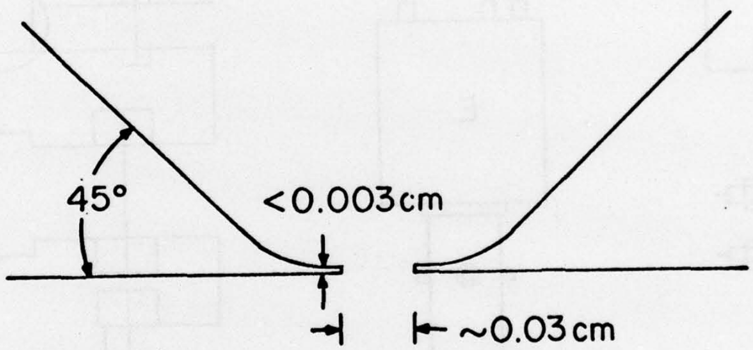

Figure 2. **Orifice Detail.**

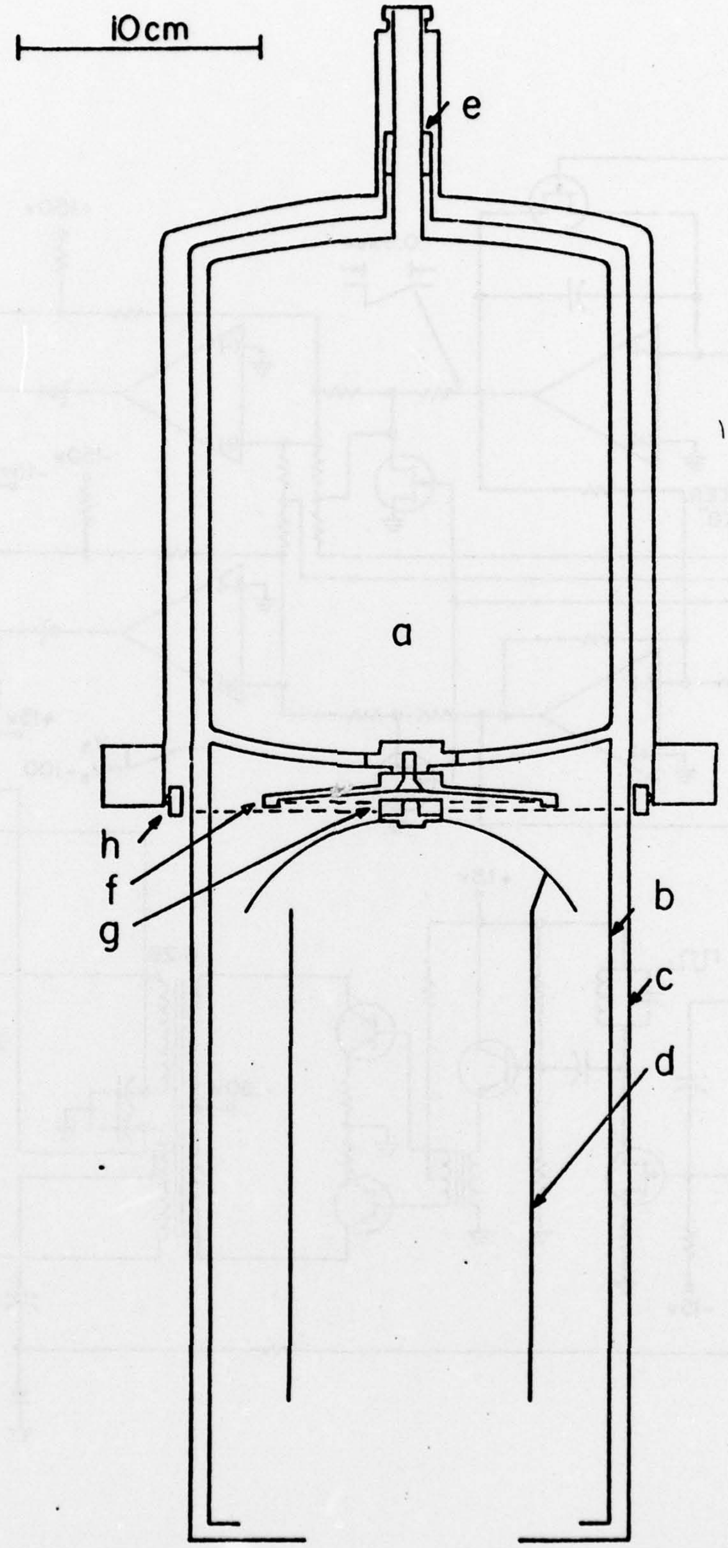

Figure 3. Helium Cryopump Schematic.

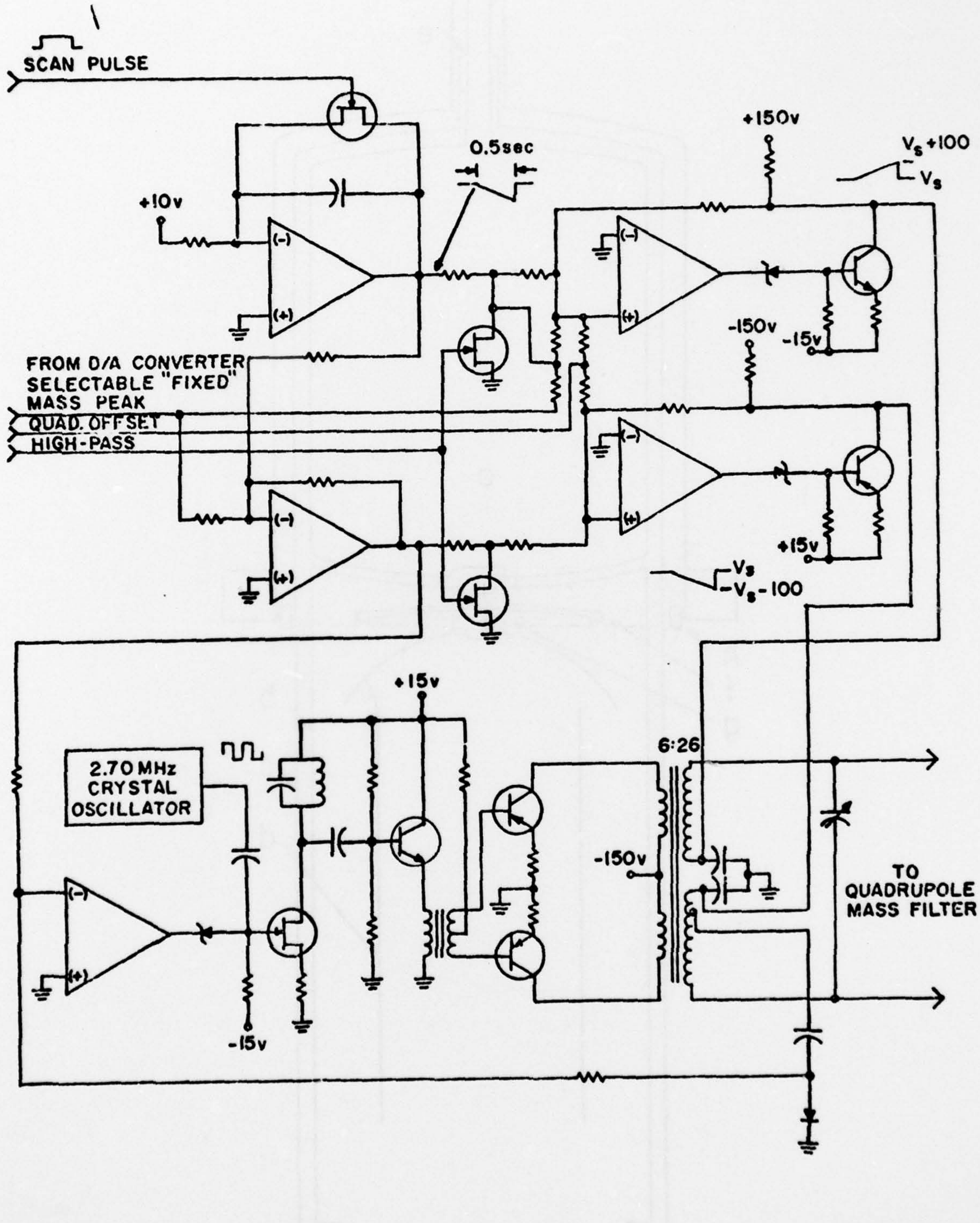

Figure 4. Simplified Solid State rf/dc Generator.

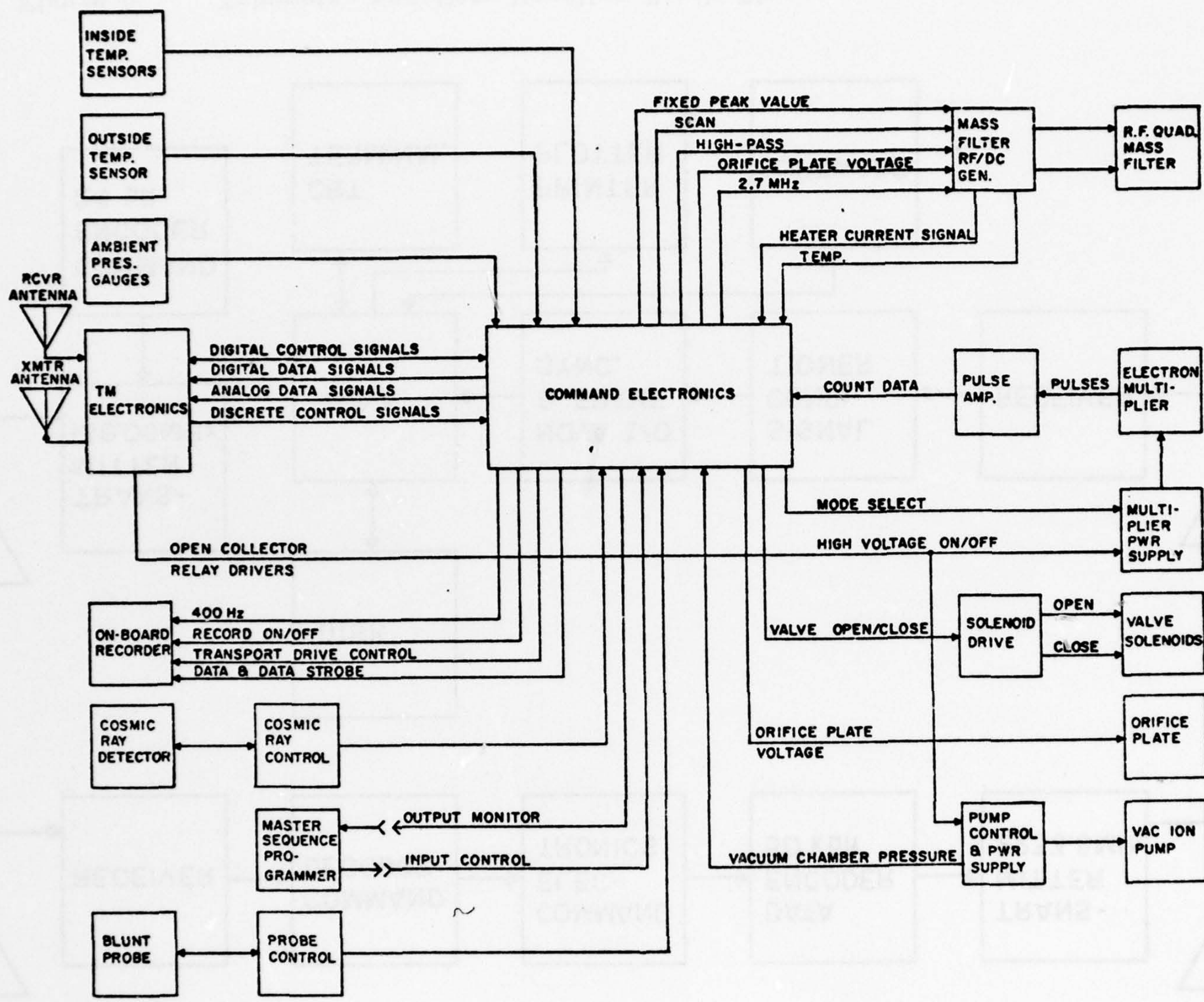

Figure 5. On-board Electronics Block Diagram.

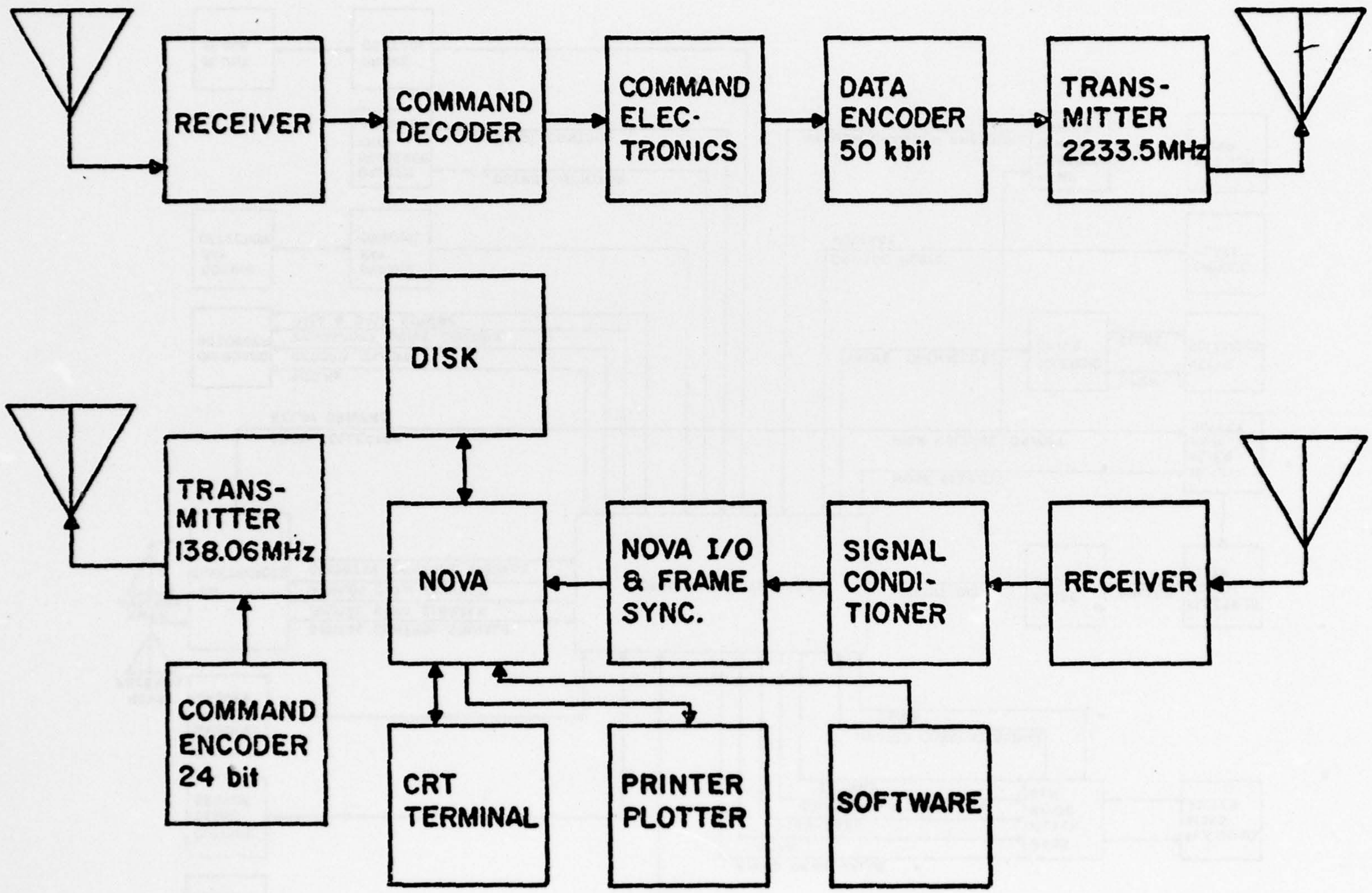

Figure 6. Telemetry and Data Handling Block Diagram.

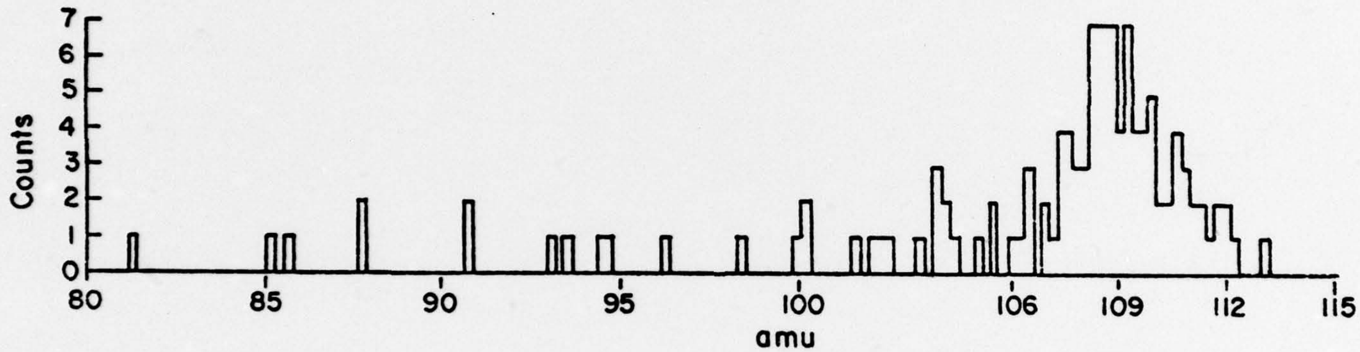

Figure 7. PI Scan Data.